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Beach-width variation at Scarborough, Western Australia

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Abstract

An analysis of beach-width changes occurring over sixteen years, from 1965 to 1981, on Scarborough Beach, in the Perth metropolitan area identifies long-term cyclic beach changes. A strong seasonal cycle of shoreline fluctuation, with the shoreline ranging up to 25 m, is superimposed on a steadier progradation of approximately 3 m per year. Other important cyclic components include a biannual component with ranges approximately 20% of the annual component and weaker 3.5 and 7 year oscillations. The several periodic components combine to cause a beat effect with a period of the order of 10 years.

Introduction

The nature of beach change on the coast of the Perth metropolitan area north of Fremantle (Fig. 1) is a matter of growing concern to State and local government authorities responsible for management of public utilities in the coastal zone. Two sets of problems are evident. Sand drift, resulting from frontal dune instability and destruction, is common in all local government areas. Car parks, roadways, parklands and buildings are occasionally buried by sand drift. Second, shoreline retreat endangers private and public property on some beaches, notably at Cottesloe, City Beach, and Floreat. The two sets of problems are related to changes in beach-width in time and space, and hence to sediment exchange between the subaerial and subaqueous beach zones. Assessment of long-term (measured over sixteen years) and cyclic variation in beach-width at Scarborough Beach is reported in this paper.

Beach profile and hence beach-width changes on open ocean sandy beaches essentially involve onshore-offshore and alongshore shifts of sand associated with changes in wave regime. Individual profile configuration alters from a berm to bar type pattern and the beach-width decreases as the wave regime alters from swell to storm wave conditions, low to high wave steepness, or reflective to dissipative wave conditions. Such changes have been examined for a variety of time scales ranging from short period duration associated with semi-diurnal tide cycles, through spring to neap tide cycles to longer period changes such as annual variations associated with seasonal weather conditions.

Beach-width also varies systematically along sandy beaches in accordance with the rhythmic topography of the nearshore zone. The rhythmic topography is linked to the beachface morphology via the nearshore water circulation system so that giant cusp horns are frequently tied to sand bars at rip catchment divides, and cusp embayments are tied to rip channels. Along a beach with rhythmic topography, beach-width changes as the pattern of rhythmic topography switches state. This occurs with variation in the wave regime or as rip currents and bars migrate along the beach.

Strategies for examining these complex beach changes have been suggested by Sonu (1969), who argued that the dynamics of beach change are best explained in terms of the collective responses of sediments associated with sand bars migrating alongshore or in onshore-offshore directions. These changes have temporal and spatial components which can be separately analysed. Temporal components may be analysed by time series analysis involving application of least squares or Fourier transform techniques (Doornkamp and King 1971; Eliot and Clarke 1980) while characteristic modes of spatial variability are identified by empirical orthogonal function, eigenfunction, analysis (Winant *et al.* 1975; Dolan *et al.* 1977; Aubrey 1979; Aranuvachapun and Johnson 1979; Bowman 1981).

Winds, waves, currents and tides

Several major weather systems determine the wind regime of the Perth Metropolitan coastal region. These have been described in detail by the Bureau of Meteorology (1969) and Gentilli (1971). Prevailing weather conditions are largely determined by a belt of anticyclonic, high pressure systems that is periodically displaced by tropical and mid-latitude cyclonic depressions or locally modified by sea breeze activity. The belt of anticyclones is seasonally displaced, alternating between latitudes 35° to 45°S in summer and 26° to 34°S in winter. The prevailing coastal winds at Perth therefore are dominantly offshore in summer and onshore in winter. This basic seasonal rhythm is modified by the other

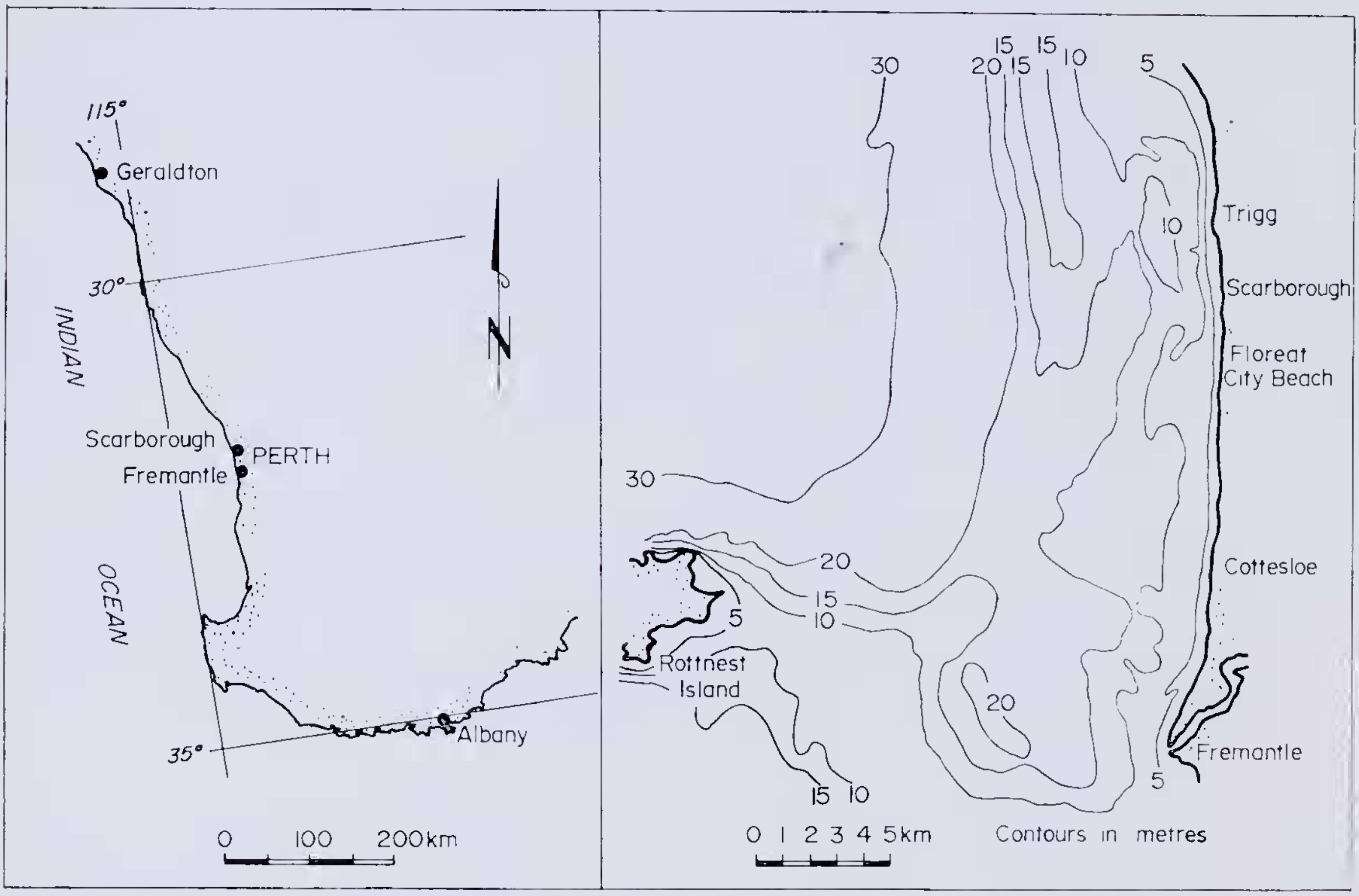

Figure 1.—Scarborough Beach: Regional Setting.

weather systems; particularly by afternoon sea breezes which blow onshore for approximately 60% of summer days (Hounam 1945). The strong seasonality of the weather regime directly affects the regional wave climate.

The coast of the Perth metropolitan area is, thus, dominated by a low to moderate energy, deep water wave regime characterised by persistent south to south-west swell (Davies 1972; Silvester 1976). The offshore wave climate has been described by Riedel and Trajer (1978) from wave data obtained in 40 m of water seaward of the Five Fathom Bank off Cockburn Sound (Fig. 1). They note that the offshore wave climate is mild, with an average significant wave height of 1.5 m. Wave heights of more than 4 m are likely to be exceeded on less than 1% of the time while heights of less than 1.0 m occur more than 80% of the time. There is little variation in the low wave energy from year to year for the summer to autumn period (December through May). However, the wave climate is more severe during the winter to spring period, with large variations possible between successive years.

Closer to shore the swell is refracted by offshore reef systems and greatly attenuated by shoaling in the inner continental shelf and nearshore environments. The reefs are discontinuous and complex wave refraction patterns develop, resulting in zones of wave convergence and divergence along the shoreline. These determine the location of large scale water circulation systems similar to those described for Californian beaches by Shepard and Inman (1950), and the development of cuspate forelands (Silvester 1976). Small shifts in wave direction, such as occur during seasonal phases of storm wave activity, cause alongshore migration of the wave convergence zones and are associated with short term reversals in the nearshore current field.

A highly variable wind-wave climate is superimposed on the swell regime. It is dominated by northwesterly storm waves during early to mid-winter, and by the wave field associated with strong, southwesterly summer sea breezes. Wave spectra for storm conditions have been described by Riedel and Trajer (1978). Storm waves in the 8 to 9 second band were superimposed on a background swell component having periods of 11 to 14 seconds. Typical spectra for sea breeze wave conditions are shown in Fig. 2.

The mixed tides of this coast have been described by Bennett (1939), Hodgkin and di Lollo (1958) and Radok (1976). Semi-diurnal constituents are dominant in the neap tide phases when tidal ranges may be less than 0.1 m, while diurnal constituents dominate the spring tide phase. Spring tidal ranges occur up to 0.9 m. Because of the relatively low range of the tide, it is frequently over-ridden by barometric pressure effects on sea level. These effects may also generate long wave activity on the continental shelf, particularly during storm conditions (Petrusevics *et al.* 1979; Allison and Grassia 1979; Allison *et al.* 1980).

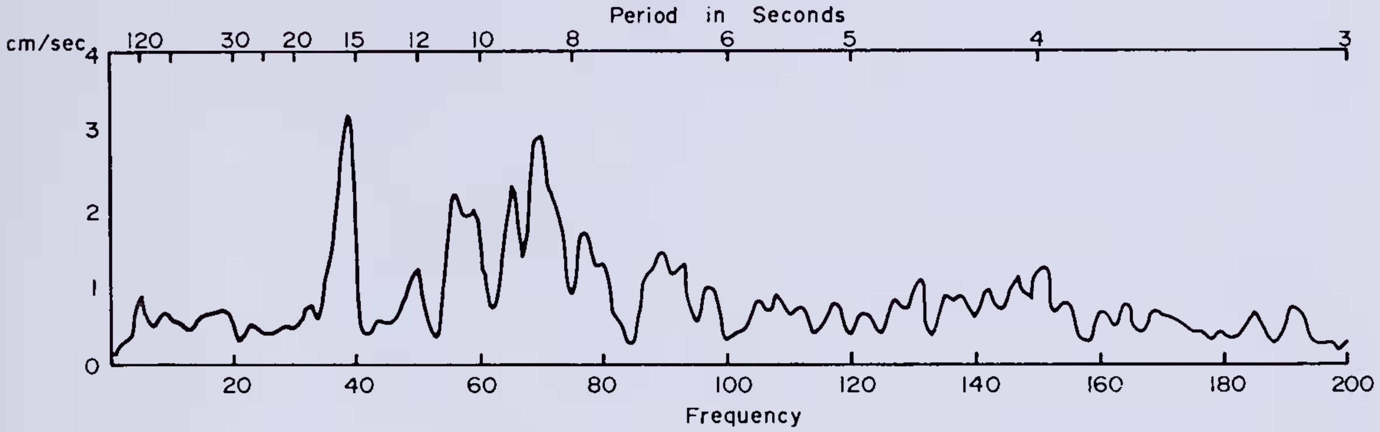

Figure 2.—Typical wave spectrum for sea breeze conditions. Amplitude spectrum for 10 minutes of bi-directional flowmeter record. Measured immediately seaward of the breaker zone at City Beach. Time 1300 hours on 21 March, 1981. Linear trend = −2.93 cm/sec over 10 minutes. Mean = −1.65 cm/sec indicating net onshore flow.

Scarborough Beach

Scarborough Beach is a salient on a large sandy beach extending 11.5 km from calcarenite headlands and reefs at North Cottesloe to similar rock outcrops at Trigg Island. The long beach is generally linear in plan form but has a rhythmic shoreline with meander wave lengths of approximately 1.2 km. Scarborough Beach is approximately 600 m long and straddles a major promontory of the rhythmic shoreline. Inshore and foreshore morphology at Scarborough is closely linked with the nearshore water circulation system, particularly with meandering alongshore currents and rips. The beach exhibits a variety of morphologic states dominated by forms similar to those described by Wright *et al.* (1979) for low wave energy conditions on New South Wales beaches. A reflective beach mode, with wide berm, steep beachface and deep inshore zone is common during summer while complex arrangements of transverse and alongshore bar patterns occur more frequently in winter. Beach sediments comprise medium to coarse grained, quartz sand with calcareous lithoclastic and skeletal material. Their composition and distribution has been described by Searle and Logan (1979).

Data collection and analysis

Beach-width has been measured at Scarborough Beach monthly since 9 August 1965, and before then intermittently since 20 May 1931. The measurements were made by chain survey of beach-width from a fixed mark seaward to the mid-swash zone for six stations spaced at 100 m intervals along the beach (Fig. 3). They provide a record of net shoreline change and cyclic fluctuation in beach-width over the sixteen years of survey. The time series of beach-width changes for profile station 4 is illustrated in Fig. 4.

The sixteen year record, 1965 to 1981, has been analysed to identify the variability and long-term change in beach-width for the six profile stations. Specifically, the following information was determined:

i The long-term trend measured over the sixteen years of observation.

ii Cyclic fluctuations thought to occur in response to seasonal variation in the wave regime and sea level elevation.

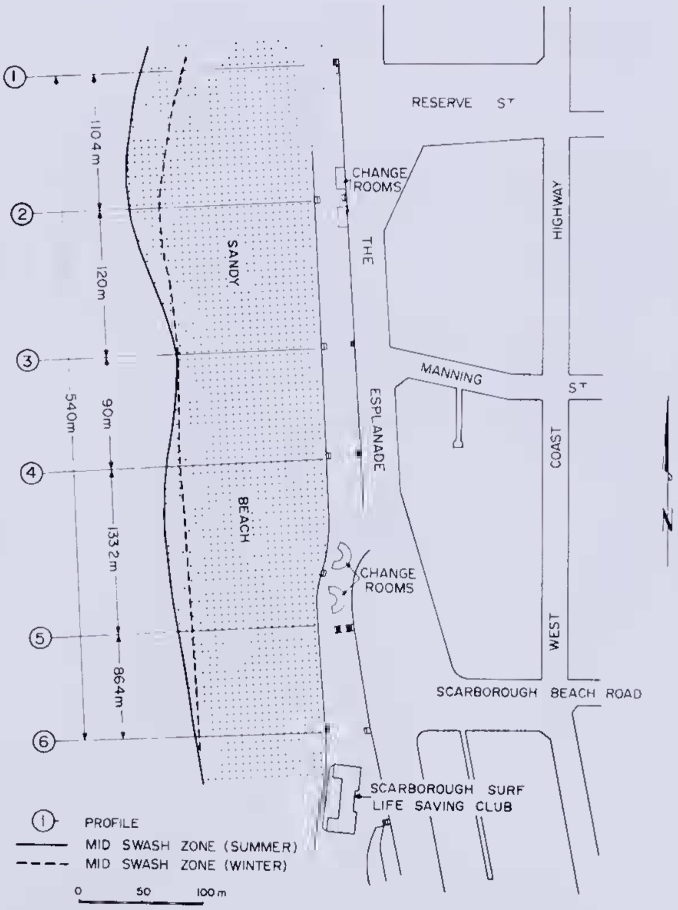

Figure 3.—Profile stations for beach-width measurement at Scarborough.

The methods of analysis used have been described previously by Eliot and Clarke (1980). They have their antecedents in work reported by Doornkamp and King (1971). The steps used in decomposition of each of the time series curves are as follows:

i The long-term trend is calculated separately for each station record by linear regression techniques. The difference between the measured trend and a state of zero net change is tested for significance in each instance.

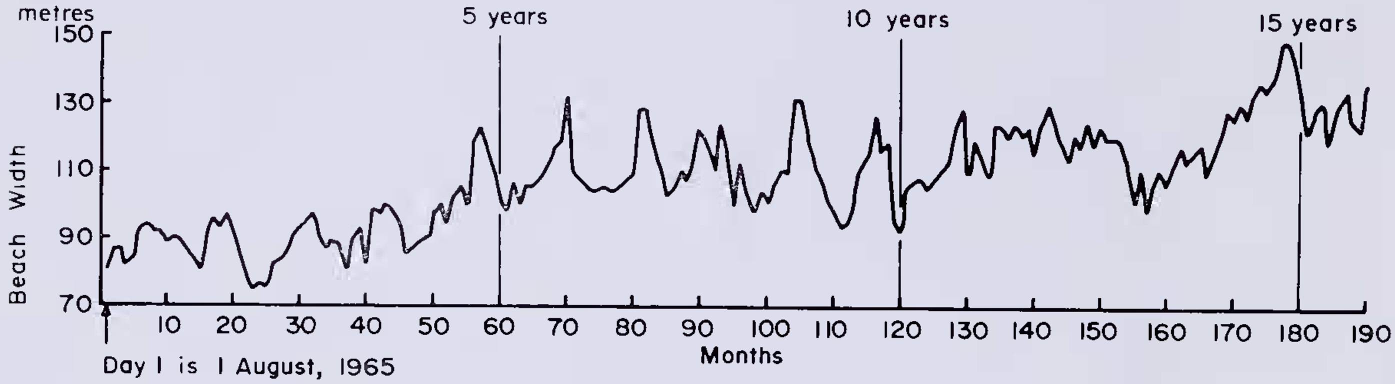

Figure 4.—Beach-width changes on profile 4, Scarborough Beach.

ii Cyclic components are then calculated by detrending the data and analysing it with Fast Fourier Transform (FFT) techniques.

Results

Long-term changes, measured as the trend of the data for each of the six stations, confirm Kempin's (1953) observation that the beach is 'building up'. Indeed, the shoreline is prograding rapidly with accretion rates ranging from 2.4 m per year on the southern end of the study area (near Scarborough Surf Life Saving Club) to 3.3 m per year at the northern end, near Reserve Street (Table 1). The mean accretion rate for all profile stations is 3 m per year.

Periodic and aperiodic variations in beach-width are superimposed on the long-term trend. The annual (seasonal) component dominates the time series with the record for each station showing a slight asymmetry. The peak beach-width is recorded in late February to early March while minimum widths are recorded in mid-August. The range of the seasonal oscillation for each profile station is listed in Table 2. It is least at Station 4, between Scarborough Beach Road and Manning Street, and increases north and south of this station. The maximum range is recorded immediately south of Reserve Street, on Station 2.

Table 1

Trend of beach-width change monitored over sixteen years, from 1965 to 1981

Profile station	Beach-width change 1965–1981 (metres)	Metres/year
1	93–146	3·3
2	89–143	3·3
3	86–133	2·9
4	87–130	2·7
5	85–128	2·7
6	90–129	2·4

Two other periodicities were evident in the record: a six monthly oscillation with ranges approximately 20% of the annual component (Table 2), and weaker 3.5 and 7 year oscillations. The biannual oscillation is probably a byproduct of the asymmetry of the annual component. However, further analysis, relating beach change to process information is necessary to test this proposition.

Discussion

Long-term progradation (measured in decades) of Scarborough Beach was postulated by Kempin (1953) and is confirmed by the 16 year trend of beach-width change on all profile stations. It raises important questions concerning the source of sediment. In this respect beach changes at Scarborough need to be set in the wider context of shoreline change between North Cottesloe and Trigg Island. Unfortunately little is known about the coastal sediment budget of this long beach. Searle and Logan (1979) have identified the principal sedimentary units but exchanges between and within these units are largely undefined. At present, the coast between North Fremantle and Trigg Island receives little, if any sediment from beaches south of Fremantle, according to Searle and Logan (1979). Sand supplied to the metropolitan beaches north of Fremantle therefore is locally derived from reworking of coastal sand dunes and from nearshore biogenic sources. North of Cottesloe the net littoral drift is northwards toward Scarborough and Trigg (Kempin 1953; Silvester 1976; Searle and Logan 1979).

Progradation in the vicinity of Scarborough Beach may be balanced by erosion in the southern sector of the Cottesloe to Trigg beach complex. However, the direction of sediment movement at Scarborough cannot be inferred from analyses reported to this paper. The spatial pattern of progradation, with progradation rates increasing in a northerly direction, is consistent with sediment accumulation on the updrift side of a shoreline obstacle, on the lee side of a major shoreline salient, or with alongshore

Table 2

Amplitudes and phases of the annual (seasonal) and biannual components of beach width variation

Profile station	Amplitude of seasonal component (metres)[1]	Phase (degrees)[2]	Amplitude of biannual component (metres)	Phase (degrees)
1	12·1	147	2·8	35
2	12·8	147	2·3	21
3	9·0	149	2·1	5
4	6·0	152	1·7	—2
5	6·4	139	1·9	29
6	6·9	147	1·3	5

[1] Maximum beach-width occurs at approximately 27 February while the minimum occurs near 27 August each year.

[2] Phase is relative to 1 October 1965.

migration of a large shoreline meander. Additionally, the long-term trend (measured in decades) may be part of much longer period, low amplitude shoreline oscillations, similar to those postulated by Stevenson (1980) for beaches of New South Wales.

An annual variation in beach-width was anticipated from a previous study of beach change on Perth metropolitan beaches by Kempin (1953). Our results confirm this expectation. The annual cycle is generally attributable to seasonal changes in coastal weather conditions, particularly with periods of strong sea breeze activity and storm onset, and with associated changes in the nearshore wave regime. Similar beach changes have been described from New South Wales by Short and Wright (1981). The contribution of particular weather systems, wave regime changes and nearshore current activity to shoreline fluctuation is subject to ongoing investigations.

The time series of beach-width change at Scarborough also has some interesting features that were not anticipated from the earlier studies. The annual cycle is slightly asymmetric with a late summer peak and a variable, mid to late winter low. It is the dominant of several periodic components superimposed on the long-term trend. The several components (12 monthly, 6 monthly and longer period oscillations) combine to cause a beat effect on the amplitude of beach change from year to year. The beat is apparent in the original data. It has a period of the order of 10 years. The amplitudes of beach change were lowest in 1967 to 1969 and again in 1977 to 1979. They were highest between 1974 and 1975.

Storm impacts on beaches are frequently identified in time series data from beach environments. Eliot and Clarke (1980) distinguished aperiodic beach changes, those related to storm impact and intermittent change in the nearshore water circulation pattern, from a five year record of beach profile data for Warilla Beach. They concluded that many aperiodic events occurred at higher frequencies than the fortnightly sampling period and produced aliasing effects in the time series. Satisfactory description of the aperiodic changes therefore, was not possible from the Warilla data. Irregularities, possibly related to aperiodic events are discernible in the time series from Scarborough Beach. However, the sampling density used was sparser than that used at Warilla and it was not possible to statistically separate aperiodic events from the longer period, cyclic beach changes. Our results indicate that monthly beach measurements do not facilitate description of the impact of storms and other aperiodic events.

Conclusions

The analysis of beach-width change over 16 years on Scarborough Beach provides quantitative description of previous expectations regarding long-term (measured in decades) and seasonal shoreline change. A strong seasonal cycle of shoreline fluctuation, with the shoreline ranging up to 25 m is superimposed on a steadier progradation of approximately 3 m per year. These changes also interact with other cyclic components and with aperiodic events, such as storm impacts and rip current migration along the beach. Other important cyclic components include a biannual component with ranges approximately 20% of the annual component, and weaker 3.5 and 7 year oscillations. Further work examining the relationship of these fluctuations to other environmental changes, particularly mean sea level variation, is in progress.

Spatial constraints limit discussion of beach change to consideration of the low frequency changes in beach-width. Effects due to the passage of particular storms cannot be clearly identified from the data. This has ramifications for the design of future studies examining beach changes associated with storm events. In circumstances such as the low energy environment of the Perth metropolitan area, high frequency (at least every second day) sampling is necessary to establish individual storm effects on beach-width variation.

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